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In vitro Biomechanical Analysis of Proximal Phalangeal Osteotomy Fixation

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Abstract

Background Corrective osteotomies of the proximal phalanx are typically stabilized with plate and screws. Although intramedullary headless screws form an alternative fixation method in the treatment of acute phalangeal fractures, reports about fixation of opening wedge corrective osteotomies with these implants are lacking.

Objective The goal of the present study was to biomechanically compare the failure force of both fixation methods for this specific indication.

Methods Twenty-four cadaver phalanges were equally distributed between apex volar and apex lateral opening wedge osteotomy groups. In each group, half of the osteotomies were fixed with a 1.3-mm dorsal locking plate, the other half with a 2.4-mm intramedullary headless screw. A three-point bending test was performed.

Results The mean maximal failure force after apex lateral osteotomy was 178.4 N for the plate-screw construct and 144.0 N after intramedullary headless screw fixation. After apex volar osteotomy, mean maximal force was 237.6 N in the plate-screw group and 160.9 N in the intramedullary headless screw group. Mean stiffness after apex lateral osteotomy was 63.3 N/mm in the plate-screw group, and 55.9 N/mm in the intramedullary headless screw group. Mean stiffness after apex volar osteotomy was 197.5 N/mm and 60.0 N/mm for the plate-screw and intramedullary headless screw group, respectively.

Conclusion For apex volar osteotomies, dorsally applied angular stable plate and screws provide significantly stronger fixation than intramedullary headless screws. For apex lateral osteotomies, fixation force is comparable.

Clinical relevance These data are useful when considering fixation of opening wedge osteotomies with intramedullary screws.

Keywords
- corrective osteotomy
- proximal
- phalanx
- intramedullary screw
- plate

Proximal phalangeal fractures of the fingers are prone to heal in malunion. Diaphyseal fractures typically present with apex volar (AV) angulation due to the pull of the intrinsic muscles.[1] Depending on the type of fracture, other angular or rotational deformities are possible. Malunions can cause aesthetic and functional problems. In case of hindersome deformity, corrective osteotomy of the malunited phalanx is indicated.

Surgical fixation of the osteotomy should provide sufficient stability to allow immediate active finger motion and preferably does not disturb the tendon apparatus of the finger to minimize the risk of postoperative stiffness.[2] Several fixation methods have been used: cross pinning[3] and plate and screw fixation.[4] More recently, the use of intramedullary headless screws (IMHS) has been described to stabilize acute phalangeal fractures.[5] The advantage of this technique is minimal disturbance of the soft tissue envelope of the finger, yet adequate stability to allow early active finger motion.

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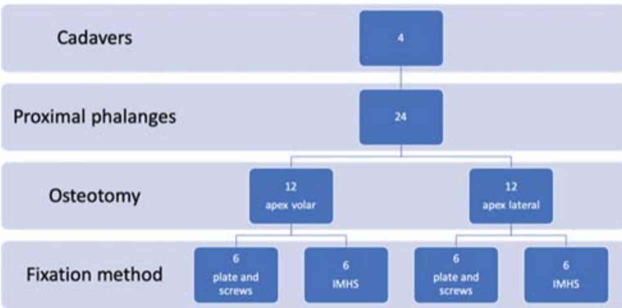

Fig. 1 Overview of the distribution of the proximal phalanges over the different osteotomy and treatment groups.

The purpose of our study is to biomechanically evaluate the stability of this new fixation method for opening wedge corrective osteotomies of the proximal phalanx and to compare this with plate and screw fixation.

Materials and Methods

Specimens

Four fresh frozen cadavers were thawed at room temperature. The proximal phalanges of the index, long and ring fingers were dissected. Thumb and small finger were not used because of their size difference. The phalanges were divided in different groups as shown in ►**Fig. 1**. For every phalanx that was fixed with plate and screws, the corresponding contralateral phalanx of the same cadaver was used for fixation with IMHS. This pairing allowed optimal comparison of both fixation methods.

Osteotomy and Osteosynthesis

Opening wedge osteotomies were created at the diaphysis of the phalanges by removing a 30 degree wedge of bone with a specially designed jig and a hacksaw. Fixation was performed with a 1.3-mm angular stable six-hole plate with two locking screws with bicortical purchase on each side of the osteotomy (DePuy Synthes, Warsaw, IN) or with an intramedullary placed 2.4-mm HCS screw (DePuy Synthes, Warsaw, IN) (►**Fig. 2**). Length of the intramedullary screw was chosen to be 6 mm less than the total length of the phalanx. Osteosynthesis material was purchased by the institutions orthopedic research fund. The manufacturer was in no way involved in the study design or execution.

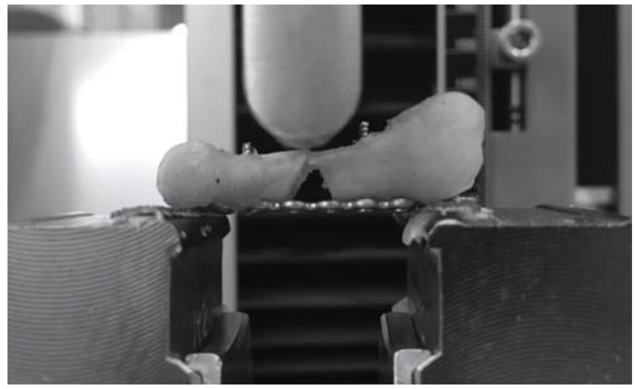

Fig. 3 A custom-made metal jig was used, acting as a stable platform on which a 3-point loading test was performed. In this case, a dorsal opening wedge osteotomy fixed with plate and screws was tested.

Testing Jig

After osteotomy fixation, phalanges from both osteotomy groups were subjected to a palmar-to-dorsal three-point bending load-to-failure test (Zwick Z2.5, range 500 N, resolution 0.005 N) (►**Fig. 3**). The phalanges were placed on the jig in such a way that no contact existed between the jigs end support and the plates, or that the horizontal projection of the intramedullary screws was within the area between the end supports. The outcome measures were maximal failure force and stiffness. Stiffness was deducted from the linear region of the loading curves. The results were normally distributed. Since we systematically used paired phalanges as control, a paired *t*-test was used to compare the results. A *p*-value of <0.05 was considered to be statistically significant. A post-hoc power analysis was performed. Approval by our Institutional Ethical Committee was obtained prior to testing (CME2018/073).

Results

The objective of our study was to compare the fixation force and stiffness of dorsal plate-screw and intramedullary screw fixation. Most forces act on the proximal phalanx in the dorsal and palmar direction. An extension force is generated on the proximal phalanx by the relatively weak intrinsic muscles. This is counteracted by stronger bending forces through the action of the flexor tendons.[6] The latter was simulated in our

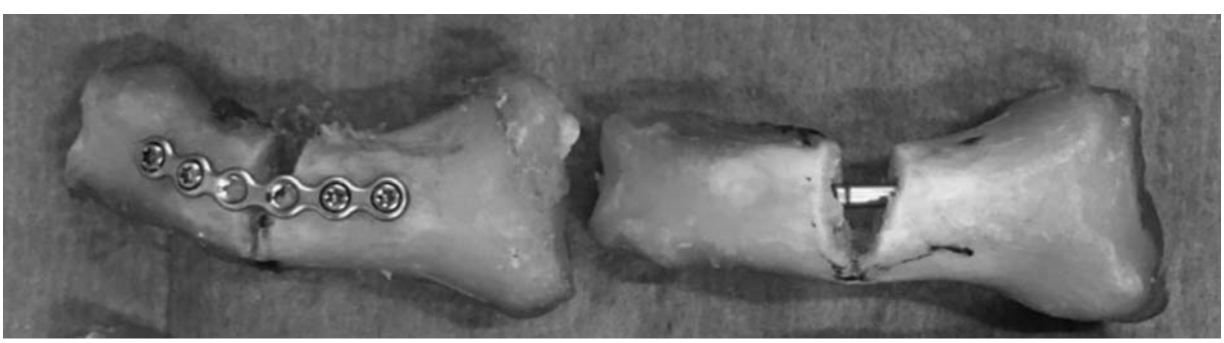

Fig. 2 Example of apex lateral opening wedge osteotomy of the proximal phalanx, fixed with 1.3mm plate and screws on the left and intramedullary headless screw on the right.

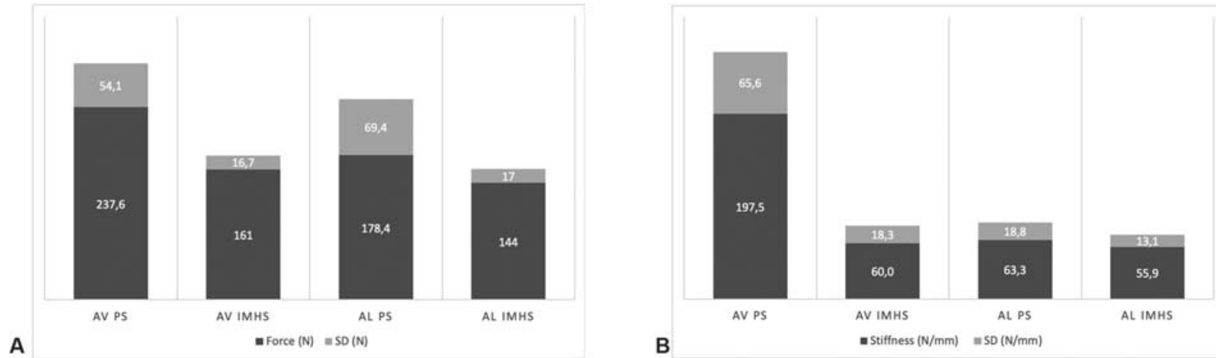

Fig. 4 Graphs showing mean maximal failure force (**A**) and stiffness (**B**) with respective standard deviations for the respective osteotomy types. AL, apex lateral; AV, apex volar; IMHS, 2.4 mm intramedullary headless screw; PS, 1.3 mm angular stable plate and screw osteosynthesis.

biomechanical experiment. The average age of the specimens was 88 years. Three were male, one was female.

Results of maximal fixation force and stiffness are shown in ►**Fig. 4**. After AV osteotomy, mean failure force and stiffness were significantly higher for the dorsally applied plate and screw group than for the IMHS group ($p = 0.008$ and $p = 0.004$). After apex lateral osteotomy, mean maximal failure force and stiffness were not significantly higher for plate and screw fixation than for IMHS fixation ($p = 0.300$ and $p = 0.236$). A post-hoc power analysis was performed. Values for the anteroposterior osteotomy were 92% (force) and 97% (stiffness), and 16% (force) and 21% (stiffness) for the mediolateral osteotomy.

Discussion

Corrective osteotomies of the proximal phalanx are typically stabilized with plate-screw constructs. The advantage of this technique is that it allows for strong fixation that is able to withstand active unrestricted motion during revalidation. The challenges associated with plate fixation are related to its location and bone healing biology. The application of a plate requires more soft tissue dissection than percutaneous techniques. Plate positioning may cause irritation of the extensor tendons and excessive screw length may cause irritation of the flexor tendons. In a series of 24 fingers that underwent plate and screw fixation after corrective osteotomy, two patients needed revision surgery due to finger stiffness.[4] In a similar setting, Abe performed a tenolysis and implant removal in two out of seven patients.[7] As shown in a cadaver model, a dorsally applied plate will displace the extensor mechanism and reduce motion at the proximal interphalangeal joint.[8] The clinical application of IMHS for fixation of corrective osteotomies has not yet been published. There are theoretical advantages to this technique over dorsal plate and screw osteosynthesis. A minimally invasive osteotomy and fixation reduces iatrogenic trauma to the soft tissue envelope of the finger and could reduce postoperative stiffness. Clinical series describe favorable results after fixation of acute phalangeal fractures with an intramedullary screw.[5] Minimally invasive corrective osteotomy of the proximal phalanx, stabilized with crossed K-wires, has been described previously.[3] The purpose of this study was to biomechanically compare plate-screw fixation and intramedullary screw fixation of opening wedge corrective osteotomies.

Our results demonstrate that after dorsal opening wedge osteotomy, plate and screw fixation has a higher maximal failure force and stiffness than IMHS. The combination of a bending force combined with an isolated palmar cortical contact area load the plate and screw construct as a tension band. In a lateral opening wedge osteotomy, lacking a palmar cortical contact area, this advantage is lost, and we found no statistically significant difference between both osteosynthesis methods. Schuind et al performed in vivo measurements of flexor tendon tension during different activities. Active unresisted finger motion created a tension of 35 N.[9] Lu et al performed an in vitro analysis of the forces acting upon a cadaver metacarpal. When loading the flexor tendons at 6 N, the dorsopalmar-directed force was 0.58 to 1.23 N.[10] Although the exact forces acting on the proximal phalanx during active unresisted motion are unknown, it seems acceptable to assume that they are lower than the maximal failure force of the IMHS constructs observed in our study (144.0–161.9 N, depending on the osteotomy orientation). Hence, fixation of a dorsal or lateral opening wedge osteotomy of the proximal phalanx with an IMHS should provide adequate stability for unresisted active finger flexion.

A post-hoc analysis showed adequate power for the anteroposterior osteotomy, and low power for the mediolateral osteotomy. This is due to the relatively large standard deviation of the results for the latter osteotomy. A larger number of specimens would have resolved this issue.

This study has several limitations. Firstly, we tested the maximal failure force and stiffness of these constructs. This does not substitute for cyclic testing, which simulates a large number of low load movements associated with unresisted motion during revalidation. However, we do believe maximal failure force and stiffness to be relevant parameters when comparing these two fixation methods. Secondly, the mean age of specimens was 88 years, which would likely be older than the patients undergoing corrective osteotomy. We believe that better bone quality associated with younger age would yield higher overall failure force and stiffness, for both fixation methods. No bone graft was used in the osteosynthesis setup, since the goal of this paper was to simulate a minimally invasive osteotomy. Clinical application of a structural bone graft would be challenging in this situation. Lastly, we tested a relatively small number of phalanges due to practical limitations.

In conclusion, our results show that dorsal plate and screw osteosynthesis is significantly stronger and stiffer than IMHS for fixation of AV opening wedge osteotomies. After lateral opening wedge osteotomy, both fixation methods do not differ significantly. Failure force and stiffness of IMHS fixation seems to be well above the estimated load on the proximal phalanx during unresisted finger flexion and should allow immediate unrestricted active finger motion after surgery. It seems justified to perform a clinical study to examine the value of this technique.

Ethical Approval

This study received Institutional Ethical Committee approval (Hasselt University, CME2018/073).

Conflict of Interest

None declared.

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